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THE INFLUENCE OF THE LEAF- GAUGE AND ANTERIOR JIG ON MANDIBULAR CONDYLES.

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A treatise submitted in partial fulfillment of the requirements for the degree of Master of Dental Science (Prosthodontics)

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Statement of Authorship

I declare that all the work presented in this treatise is my own, unless otherwise stated. The work of colleagues is acknowledged in general terms within the Acknowledgements and specifically within the body of the text, wherever it is appropriate.

MILAD AZIZI

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# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Literature review</strong></td>
<td>5</td>
</tr>
<tr>
<td>Introduction</td>
<td>6</td>
</tr>
<tr>
<td>1. Centric relation (CR)</td>
<td>6</td>
</tr>
<tr>
<td>1.1 CR registration methods</td>
<td>10</td>
</tr>
<tr>
<td>1.1.1 Anterior jig</td>
<td>12</td>
</tr>
<tr>
<td>1.1.2 Leaf-gauge</td>
<td>13</td>
</tr>
<tr>
<td>1.2 Anterior teeth relationship</td>
<td>15</td>
</tr>
<tr>
<td>2. Bite-force and CR</td>
<td>15</td>
</tr>
<tr>
<td>2.1 Jaw muscle activity and CR</td>
<td>16</td>
</tr>
<tr>
<td>3. Recording of condyle position</td>
<td>18</td>
</tr>
<tr>
<td>3.1 Condylar position of CR recordings</td>
<td>21</td>
</tr>
<tr>
<td>3.2 JAWS-3D</td>
<td>23</td>
</tr>
<tr>
<td>3.2.1 Accuracy of JAWS-3D</td>
<td></td>
</tr>
<tr>
<td>Conclusion</td>
<td>24</td>
</tr>
<tr>
<td>References</td>
<td>25</td>
</tr>
<tr>
<td><strong>Research project</strong></td>
<td>29</td>
</tr>
<tr>
<td>Introduction</td>
<td>30</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>32</td>
</tr>
<tr>
<td>1. Participants</td>
<td></td>
</tr>
<tr>
<td>2. Anterior jig construction</td>
<td></td>
</tr>
<tr>
<td>3. Leaf-gauge recording</td>
<td></td>
</tr>
<tr>
<td>4. Jaw movement recording</td>
<td></td>
</tr>
<tr>
<td>5. Tasks</td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td>38</td>
</tr>
<tr>
<td>Discussion</td>
<td>44</td>
</tr>
<tr>
<td>1. Condylar displacement</td>
<td></td>
</tr>
<tr>
<td>2. The accuracy of JAWS-3D</td>
<td></td>
</tr>
<tr>
<td>3. Biting on the leaf-gauge</td>
<td></td>
</tr>
<tr>
<td>4. Biting on the anterior jig</td>
<td></td>
</tr>
<tr>
<td>Conclusion</td>
<td>51</td>
</tr>
<tr>
<td>References</td>
<td>52</td>
</tr>
</tbody>
</table>
Literature Review
Introduction

The leaf-gauge technique is used in dental practice for the registration of jaw records in centric relation. The leaves are placed between the incisor teeth and held with varying degrees bite-force. Leaves are added to ensure that the posterior teeth are not in contact. It is claimed that this procedure allows for greater ease in jaw guidance and ensures that the condyle is in its most stable position for recording purposes.

Several studies have attempted to identify the effect of the leaf-gauge and the anterior jig on the condyle position (Carr et al 1991, Williamson et al 1980, Lundeen 1974, Hellsing & McWilliam 1985, Golsen and Shaw 1984). Conversely, the effect of various incisor relationships has not been adequately addressed. Research is necessary to define the action of the leaf-gauge, which may lead to confirmation or modification of the technique.

1. Centric Relation (CR) or median retruded relation, retruded contact position, retruded axis position.

The definition of CR has undergone substantial changes over the past 50 years (Glossary of Prosthodontic Terms 1956, 1960, 1968, 1977, 1987, 1994, 1999), despite the fact that the same methods are used and claimed to be valid and compatible with recent definitions.

The ever-changing definition of CR highlights the difficulty of clinicians and academics to study the dynamic functional movement of the condyle, as asked by Keshvad and Winstanley (2000), "Perhaps it is the temporomandibular joint (TMJ)
that adapts itself to the scientists' definition each time it changes, or is the TMJ accepting any position?”

The Glossary of Prosthodontic Terms (5th edition) in 1987, introduced the change from the most postero-superior position to the most antero-superior position. Little research has been conducted since to validate or confirm this statement.

One of the current definitions of CR according to the Glossary of Prosthodontic Terms from the Academy of Prosthodontics (1999) is “the maxillomandibular relationship in which the condyles articulate with the thinnest avascular portion of their respective disks with the complex in the anterior-superior position against the slopes of the articular eminences. This position is independent of tooth contact. This position is clinically discernible when the mandible is directed superiorly and anteriorly. It is restricted to a purely rotary movement about the transverse horizontal axis”.

According to Celenza (1973), “most disciplines in dentistry favour CO as the most acceptable interdigitative tooth position”. Centric occlusion is the tooth contact position when the condyles are in centric relation and this is the relationship that Celenza was describing. In this context prosthodontists are often faced with the dilemma of treatment of severely disorganized occlusions, where there is a need to determine a jaw position that is reproducible for treatment and physiologically stable.

The retruded position (RP) is the spatial position of the jaw when the condyles are located in their close-packed position within the glenoid fossa at an acceptable
vertical dimension of occlusion. Ideally, RP should be the position of the mandible at
tooth contact where the condyles are in a physiologically acceptable position (i.e.
biologically stable but not a fixed position long-term) for reproducible transfer
recordings (Klineberg 1991). This jaw position is specific for each individual. RP
describes the jaw position with the condyles in CR.

Many studies report that CR is the ideal treatment position, however the need for
recording CR depends on the clinical treatment required. In a descriptive paper on
CR, Carroll et al (1988) stated that the significance and advantages of being able to
place the jaw and condyles into CR are as follows:

1. “CR is usually an easily reproducible and comfortable position.”

2. “When the condyles are retruded, the mandible is capable of repeatedly
   making a purely rotational movement through an incisal separation of 10-25
   mm permitting location and transfer of this axis to an articulator.”

It is not possible for the condyle to be retruded yet at the same time be in CR. The
condyle may be guided repeatedly along a rotational path whilst in CR as it is braced
against the eminence.

3. “Patients appear to function comfortably in CR, after CR occlusal
   equilibration, after full mouth rehabilitation, during occlusal splint therapy and
   wearing complete dentures.”

Occlusal equilibration, which is usually directed at removing the IP-RP slide, may
often require extensive tooth reduction to harmonize the tooth contact position in CR.
This provides a specific occlusal scheme. Extensive tooth reduction is questionable and not recommended (De Boever et al 2000).

Full mouth rehabilitation, may involve the establishment of a new vertical dimension of occlusion and requires the use of CR (Becker et al 2000). The CR record is often taken using the bimanual guidance technique with the patient in the supine position (Dawson 1989). CR must be comfortable, repeatable and involve condylar rotational movement.

Stabilizing occlusal splints are designed to have flat contact surface with opposing cusp tips; this does not restrict the jaw to CR. In the case of complete dentures, the instability of the denture bases does not require a restricted occlusion. However, there is a need for stability in IP (jaw position at which the teeth are in static contact) and balanced contacts in lateral excursions. An ideal complete denture occlusion should enhance the stability of the bases as indicated by Fish (1952).

4. “Numerous TMJ disturbances, including pathological changes, may occur or are triggered when malocclusion exists because of tooth movement, dental restorations or inadequate orthodontic treatment.”

It has been clearly shown by Pullinger et al (1993) that “occlusion cannot be considered the unique or dominant factor in defining temporomandibular disorder (TMD) populations”. In addition, Sim et al (1995) concluded in their review paper “there is no increased risk of TMD associated with any type of orthodontic mechanics”.

5. “Patients with painful TMJs frequently report surprisingly quick relief of their pain and other symptoms after wearing an occlusal splint, biting on a leaf-
gauge for several minutes or after a dentist has removed the tooth or teeth which were prematurely contacting in the CR position.”

Dao et al (1994) concluded in their controlled clinical trial, on the efficacy of oral splints in the treatment of myofascial pain of the jaw muscles, “the gradual reduction in the intensity and unpleasantness of myofascial pain, as well as the improvement of quality of life during the trial was non-specific and not related to the type of treatment.” Barghi et al (1979) also concluded that occlusal discrepancies causing lateral deflection of the mandible might not be a sufficient etiological factor in either nocturnal bruxism or myofascial pain dysfunction.

The question arises as to whether the jaw position obtained by different jaw guidance techniques was biologically acceptable to the neuromuscular system in the long-term. Each technique claimed to allow accurate maxillo-mandibular relationship recordings. Despite research studies to determine condylar position during CR recordings, it has proven to be difficult.

1.1 Centric relation registration methods

Different methods have been described in the literature. In her review article Dixon (2000) described 4 categories of recording CR for complete denture construction:

1. Direct interocclusal records

These have been referred to as physiologic records. Of importance to the success of the direct recording method is the dentist’s ability to recognize CR position and that the recording material directly influences the pressure
developed in the recording. Swallowing was often used as a guide to obtain CR in complete dentures.

2. Intraoral and Extraoral graphic recordings

These recordings include Gothic arch (arrow point tracings), which apply mostly to complete denture construction.

3. Functional recordings

Functional methods of recording CR were designed to attempt to record the jaw relationship physiologically without operator guidance. Under these conditions there was a need for the bases to be particularly stable. If the base was dislodged, the record will obviously be inaccurate. Some clinicians including Boos (1954) used maximal biting pressure to simulate functional biting positions. However, Boos changed his mind later and recommended CR records be taken with no pressure or torsion.

4. Cephalometrics

These radiographs have been used to determine CR and the appropriate vertical dimension of occlusion. This practice, however, has not gained widespread application.

According to Dawson (1989) who described the use of a bilateral manual technique, the temporomandibular ligament appears to act as the posterior limit and fulcrum. He claimed that the downward force of the thumbs on the chin together with the upward
supporting force of the fingers along the lower border of the jaw help to seat the condyles in the antero-superior portion of the glenoid fossa.

1.1.1 Anterior Jig

The anterior jig was first introduced by Lucia (1964) to facilitate interocclusal records. The jig is usually made of auto-polymerising acrylic resin on mounted casts and adjusted in the mouth. Lucia indicated that clinical adjustment was necessary to train the patient in easily guided hinge axis closure. By repeated adjustment, it was assumed that the patient would bring the condyles to their uppermost position against the articular eminence and rearmost to the full extension of the temporomandibular ligament. The adjustment was accomplished, according to Lucia, by marking with carbon paper. The patient was instructed to move the mandible forward and backward and to each side to scribe a Gothic arch. With a rubber wheel the wings and the tail of the tracing were carefully removed, until only a circle at the apex is left. It was preferred that the jig had a slight upwards and backwards slant on the surface in order to make it easier to hold the position while CR is recorded.

Lucia claimed “the jig disconnects the reflex circuit, thereby preventing the patient from making incorrect closures of long-standing habit”. The jig was believed to eliminate proprioceptive responses, to permit the muscles to act freely and to allow the condyle to be moved into an unstrained position. It was presumed that the muscles will then rotate the mandible anteriorly and superiorly.

Such claims cannot be substantiated since neurophysiological research indicates that neuromuscular control of jaw movement is not only influenced by dental and
periodontal sensory input. Feedback from the muscles, joints, ligaments, periosteum and skin also play a role.

Other clinicians used the jig for relaxation of jaw muscles and relief of muscle pain (Long 1995). It was claimed that as the jig was engaged by the lower incisors with the closing muscles continuing to contract, the condyles were more likely to be seated in their middle and most superior positions (Carroll et al 1988).

Klineberg and Murray (1999) refer to McCloskey (1978) who described the process of “corollary discharge” which was thought to provide the sensation of muscular force or effort, which accompanied centrally, generated voluntary motor commands, such as voluntary biting. These authors indicated that in edentulous individuals, muscle spindle afferents may provide the dominant control supported by afferents from TMJ capsules and mucosal-periosteal mechanoreceptors. Despite the loss of teeth, most complete denture users appear to adapt and develop an altered pattern of jaw control to allow function. However, a proportion of individuals have adaptation difficulties leading to ongoing complaints about prosthesis inadequacy (Fiske et al 1998).

1.1.2 Leaf-gauge

Long (1973) described the leaf-gauge which consisted of leaves (usually ten) of acetate or other plastic material, 0.1mm thick. The leaves were placed between the anterior teeth and more leaves added until no posterior tooth contact was felt. Separation of the posterior teeth for a sufficient period of time (as yet to be determined) was alleged to allow a stable position of the jaw and condyles. Long claimed that as posterior tooth contacts were eliminated, feedback mechanisms
changed and CR record could be more readily recorded. According to Long, this minimized the error caused by transferring the clinical record to an articulator, which was usually caused by the thickness of the wax. The deviation in the closing path was reduced because the closing distance to bring the teeth into contact was minimized by the thickness of the leaf-gauge. The main difference between the anterior jig and the leaf-gauge is that the latter allows easy adjustment to secure minimal separation of the posterior teeth.

Golsen and Shaw (1984) also described "tripodation" of the mandible with the leaf-gauge and condyles forming the three components of the tripod, which may allow the musculature to function freely without proprioceptive guidance from tooth contacts (Fig 1). These authors believed condyle position to be midmost, rearmost and uppermost. However, this condyle position suggests that the condyle was not in contact with the eminence, which does not comply with the suggested optimal position that was described by Dawson (1989) and Klineberg (1991).

Figure 1: Tripodation of the mandible with the leaf-gauge. The two condyles and the leaf-gauge form the tripodation of the mandible (Golsen and Shaw 1984).

Fenlon and Woelfel (1993) analyzed condylar position by taking interocclusal records using a leaf-gauge and controlled occlusal forces. They found that tripodisation with
the leaf-gauge resulted in displacement of the condyles in a superior direction with little antero-posterior movement.

1.2 Anterior teeth relationship

Golsen and Shaw stated several contraindications to the use of the leaf-gauge:

“

1. Class II div II malocclusion
2. Patients with history of traumatic injury to the TMJ or TMJ surgery.
3. Patients with intracapsular pain on palpation dorsal to the TMJ”.

In their opinion, with Class II div II malocclusion, the condyles were more likely to be displaced “down and back if an inclined plane was placed between the incisors”. In our study we aimed to select a subject with Angle Class II Div II incisor relationship in order to address our hypothesis that the condyle will not move postero-inferiorly. On the other hand, interocclusal records should not be taken when TMJ pain is present.

2. Bite-force and CR

Williamson et al (1980) conducted a study to monitor the effect of bite-force on the position of the condyles during CR recording. They used a leaf-gauge to eliminate posterior tooth contact, then asked the subjects to bite with different pressures to observe any difference in condylar position. Electromyography was used in their study to indicate muscle activity in biting on the leaf-gauge, and “influencing jaw position”. They concluded, “Interocclusal record made with the patient biting easy on the leaf-gauge appears to allow physiologic placement of the condyles in the glenoid
fossa”. “The temporals muscles have more influence upon CR condylar position than the masseter muscles when an anterior guidance appliance is used”.

Williamson and his colleagues only measured the activity of the temporals and masseter muscles and used a Vericheck (Vericheck, Denar Corp, Anaheim, Calif.) to assess condyle position. The lateral and medial pterygoid muscles may also have had significant influence and the Vericheck does determine condyle position accurately.

Golsen and Shaw (1984) recommended that the bite-force applied to the leaf-gauge should be the same as that exerted during swallowing. The use of swallowing was firstly to train subjects to bite with the same force on the leaf-gauge; secondly, the authors believed that excessive bite-force could force one or both condyles inferiorly and posteriorly. It seems that they concurred with Williamson and his colleague’s (1980) conclusion that “Intercclusal records made with the leaf-gauge and with the patient biting hard tend to cause mandibular condyles to be forced posteriorly and away from the articulating surface of the eminence”.

2.1 Jaw muscle activity and CR recording techniques

Duthie & Yemm (1982) showed that, with the head erect, “active” (i.e. by the patient) CR positioning induced activity in both temporal muscles and in the supra-hyoid and infra-hyoid muscles, with little contribution from the masseter and lateral pterygoid muscles. It was also shown that the anterior temporal appeared to act as a “stabilizer”, while the middle and posterior temporal retruded the mandible in association with the supra-hyoid muscles.
The infra-hyoid muscles stabilized the hyoid bone and the lateral pterygoid muscle stabilized the temporomandibular disc.

Murray et al (1999) studied the electromyographic activity of the human lateral pterygoid muscle during contralateral and protrusive jaw movements. The concluded that:

1. The lateral pterygoid was the major jaw muscle that moved the condyle downwards and forwards during contralateral movements and was an important muscle in protrusion.

2. The variation in electromyographic data between participants may reflect the different neural strategies required to control muscle movement in individuals with different facial morphologies and skeletal muscle architectures.

3. The inferior head of the lateral pterygoid muscle tended to be more active than the superior head in moving the condyle forward along the articular eminence during protrusion and contralateral movements.

Carr et al (1991) conducted a three-dimensional electrognathographic study of an incisor point to “detect peripheral correlates of the jaw elevator muscles”. This was interpreted this to mean the influence of jaw position and other variables on jaw muscles.

A leaf-gauge was held comfortably for 10-15 minutes between the incisor teeth which disclued the posterior teeth by about 2 mm. They concluded that on the basis of electromyography and electrognathography, the short-term and non-fatiguing use of a
leaf-gauge would not alter normal mandibular movement patterns and normal contraction patterns of jaw muscles. They were unable to demonstrate a so-called “adaptive” jaw closure pattern that was changed through use of a leaf-gauge. This conclusion questions the basis for the use of the leaf-gauge as a jaw muscle “deprogramming” device, as proposed by Long (1973).

3. Tracking of condyle position

3.1 Condylar position and CR recording

Klineberg (1991) listed the several points that relate to optimal condylar position:

1. “The spatial relationship of the condyle and the temporal component is variable in different individuals.

2. The optimum position is the one that works best for the individual.

3. Anatomical features indicate that the functional relationship is between condyle and posterior slope of eminence. Since the interarticular disc is thinnest in the middle of its central beating surface, the optimum functional position of the condyle is therefore with the condyle more closely aligned to the eminence than to the fossa.

4. Condyle position in the adult is a result of adaptation to a state of biological harmony between the jaw muscles and the dental arches with the correctly aligned interarticular disc. From a functional point of view it is the condyle-eminence relationship that is important and not the condyle-fossa.”
Many methods have been used to determine condylar position during variable jaw relationships or jaw manipulation techniques.

Hobo and Iwata (1985) analysed condylar position achieved by three common methods of CR recording. They used a recording device that consisted of a three-dimensional optical sensor, a point light source, stainless steel upper and lower clutches, an attitude meter (a facebow look-alike that measures the position and the inclinations of the clutches in the mouth towards reference planes) and a microcomputer. When the mandible was in CR, the three-dimensional static positions of the point light source were recorded with an accuracy of 40 μm. The distances between the central bearing point, the terminal hinge axis and horizontal plane were measured. A mathematical formula was then used to compute the location of the condyle. They reported the data as follows:

1. Chin guidance placed the condyle in the most posterior and superior position. The record was made by a combination of the patient’s musculature and operator guidance.

2. Bilateral operator guidance.

3. Non-operator guided technique or guided by the jaw muscles.

They concluded that the bimanual operator guidance technique showed the most consistent repeatability. It allowed the operator to guide the condyles into an antero-superior position in apposition with the articular disc against the articular eminence. They did not recommend the use of chin point guidance because they believed that it has potential harmful effects on the bilaminar zone. Chin point guidance located the condyle 0.3 mm posteriorly, 0.1 mm inferiorly and 0.13 mm laterally. Hobo et al
claimed that trauma to the bilaminar zone may be a possible contributor to anterior disc displacement. These authors described a condyle position that has since been shown to be inaccurate due to the use of one-point calculations (Peck et al 1999).

The chin point guidance technique used was not described, which further weakens their conclusions. The traditional chin point guidance has been in use for years with no indication of any harmful effect. In addition, clinical experience has shown that in healthy joints, the joint ligaments and jaw muscle tone prevent possible “trauma” to the posterior attachment tissues associated with clinical recordings.

Hellsing et al (1985) used subtraction radiography to determine condyle position with one-handed chin guidance. They concluded, “The mandibular condyles are seated in a reproducible position well suited as a registration of CR”. Braun et al (1997) used a standardized lateral cephalostat to determine condyle position when registering CR. They assessed CR recordings taken with either leaf-gauge or mandibular guidance. They concluded that both methods failed to position the condyles reliably in their terminal hinge position. The condyles were found to be located in a variety of locations regardless of the method of clinical management of the jaws.

Klineberg (1991) considered both methods described above for imaging condyle position to be inadequate and stated that a three-dimensional position cannot be accurately recorded with a two-dimensional radiograph. Eckerdal and Lundberg (1979) also showed that variations in condylar position observed on radiographs, may simply reflect the variation of the shape of the osseous components of the same joint from its medial to its lateral aspect.
Alexander et al (1993) assessed condylar position by using articulator mountings and magnetic resonance imaging (MRI). They discussed that in many situations the two methods failed to correlate statistically. They claimed that these differences might be explained by the lack of a sharp demarcation of cortical bone on the MRI image that reduced the accuracy of the measurements. In addition, small measurements and large variations potentially created small changes in interpretations of either method.

3.2 JAWS-3D

Clinical recording and interpretation of condylar movement have been made mostly on the basis of the movement of a single condylar point, such as the palpated lateral condylar pole.

Peck et al (1999) used an opto-electronic jaw tracking system (JAWS-3D, Metropolis AG, Zurich, Switzerland) to track the movement of a condylar point 15 mm medial to the skin over the palpated lateral condylar pole. This latter was called the primary condylar point to be used for data display. For each movement task, computer data files were created and contained anteroposterior (x), medio-lateral (y), and superoinferior (z) positions, of each condylar point with respect to time. Arbitrary condylar squares (ACSs) were constructed in the sagittal and horizontal planes by selecting 4 additional points as the squares’ vertices. Each of these additional points was 5 mm from the primary point.

Radiographic markers consisted of gutta-percha mounted at 5 mm intervals in a Perspex frame. The markers were accurately positioned adjacent to the skin overlying the right TMJ. On axial computer tomographs the most anterior, posterior, and lateral condylar poles were determined. Standard matrix transformations enabled the
determination of computerized tomography-derived condylar landmark coordinates within the coordinate system of JAWS-3D.

A radiographic condylar triangle was constructed in the sagittal plane by joining anterior, posterior and superior condylar points, and a radiographic condylar quadrilateral was constructed in the horizontal plane by joining anterior, posterior, medial and lateral condylar points. After aligning the trajectories of these points for the jaw movements, in their correct spatial orientation, resultant ACSs and radiographic condylar triangles and quadrilaterals were plotted every 300 ms. Subjects, seated upright, moved their jaws allowing the target frames to be tracked by three optical sensors.

In their study on the trajectories of condylar points during working side excursive movements Peck and colleagues (1999) concluded that:

"  
1. It is not possible to accurately record the magnitude of condylar displacement based on the movement of a single condylar point.
2. To accurately describe the movements of the working-side condyle, the trajectories of at least 3 radiographically determined condylar points should be calculated from mandibular movements recorded with 6 degrees of freedom.
3. In jaw movements involving appreciable rotation such as open-close different condylar points in the vicinity of the instantaneous center will move in different directions depending on their location with respect to the center."

22
This study is especially significant as it defines for the first time what is necessary in assessment of condyle position.

Ferrario et al (1996) in their study on the open-close movements in the human TMJ indicated that the condyle centre of rotation was movable during every phase of the habitual jaw movements and the instantaneous centre of rotation replaced the hinge theory. They also stated “in a sagittal plane view, the opening movement is described as the sum of gliding and rotating components, whose reciprocal magnitude varies as the opening angle increases”.

Both studies by Peck et al and Ferrario et al confirm the difficulties and errors that can be encountered in the measurement of condylar movements, if the reference was a single point.

3.2.1 Accuracy of JAWS-3D

Airoldi et al (1994) examined the accuracy of JAWS-3D recordings. The results showed that the accuracy of JAWS-3D decreased when the distance between the recorded point and the extraoral landmarks increased. The path of a point near the landmark was estimated with an error of 0.11%, whereas the error increased to 1.33% when the point was far from the landmarks. The maximum error in angle computation was 0.7 degrees. The velocities calculated by JAWS-3D corresponded closely to the actual ones: mean error of 3 mm/s for velocities up to 80 mm/s (3.75%). Thereafter, the error increased to 26 mm/s at a speed of 210 mm/s (12.39%). Airoldi and colleagues concluded that the small error of JAWS-3D together with its low invasiveness supported its use in clinical research.
Conclusion

It is clear that both confusion and ambiguity surround the use and recording of CR position. Some clinicians are enthusiastic about the use of the leaf-gauge and anterior jig, whereas others remain cautious. In our study we aim to examine several aspects in relation the use of these devices, including condylar position at various bite-force and the effect of incisor relationship. This is to be a pilot study that will hopefully form the basis of further larger studies.
References:


Research Project
Introduction

Centric relation (CR) remains one of the more controversial issues in prosthodontics with debate and opposing ideas amongst scientists and clinicians. Periodically, a clinician presents a new recipe for recording CR to replace all the previous methods. However, it is realized that similarities between the methods exceed the differences.

A significant change in the definition was included in the Glossary of Prosthodontic Terms (5th edition) in 1987, with the change from the most postero-superior position to the most antero-superior position.

The current definition of CR from the 1999 Glossary of Prosthodontic Terms from the Academy of Prosthodontics is “the maxillomandibular relationship in which the condyles articulate with the thinnest avascular portion of their respective disks with the complex in the anterior-superior position against the slopes of the articular eminencies. This position is independent of tooth contact. This position is clinically discernible when the mandible is directed superiorly and anteriorly. It is restricted to a purely rotary movement about the transverse horizontal axis”.

Prosthodontists are often faced with the dilemma of treatment of severely disorganized occlusions. The need to determine a reproducible jaw position is valuable during treatment and for physiological stability. In the literature there are many methods that claim to achieve CR such as swallowing or free closure
(Shanahan 1955), chin point guidance (Helkimo 1971), chin point guidance with anterior jig (Lucia 1964), bimanual manipulation (Dawson 1989), Gothic arch tracings (Pleasure 1955) and leaf-gauge (Long 1973). Williamson et al (1980), comparing biting hard on leaf-gauge during tripodisation, found little difference between condylar displacements in a superior direction, but reported that biting hard caused significant posterior displacement. Further research is required to study the displacement of the condyles when using the leaf-gauge.

Hypothesis:

This pilot study is to consider that:

The use of a leaf-gauge or anterior jig realigns the condyles reproducibly.

Aims:

To investigate that:

1. Biting on a leaf-gauge at maximum and half-maximum bite-forces will place the condyle in the defined CR position

2. Biting on an anterior jig at maximum and half-maximum bite-forces will place the condyle in the same defined CR position.

3. Biting on the leaf-gauge where an Angle Class II div II incisor relationship is present will not displace the condyles postero-inferiorly.
Materials and Methods

1. Participants

Five volunteers were selected from dental students and staff (all males, with age range 23 to 32 years), without signs or symptoms of craniomandibular disorders (for criteria, see Klineberg, 1991). Informed consent was obtained from all participants. The Western Sydney Area Health Service Ethics Committee of Westmead Hospital and the Human Ethics Committee of the University of Sydney approved experimental procedures. Alginate impressions were taken and plaster models of upper and lower jaws were made for each participant. From the study models an anterior jig and upper and lower clutches for condylar recording were constructed.

Three pilot recordings were performed on 2 subjects, twice on subject RS and one on subject MA. Eight recordings were performed in total. The data from the first three recordings were used to refine the recording techniques and were excluded from the final analysis. In one subject (subject PA) data for the condylar movements could not be used due to a technical problem during the trial.

Subjects RS, SF and PA had Angle Class I incisor relationships with minimal overjet and overbite. Subject MA had Angle Class II div 2 incisor relationship with a deep (60%) overbite, whilst subject SP had a Class III (edge to edge) incisor relationship.

2. Anterior Jig Construction

A 102kgf (1kN) (Kyowa Corp, Japan) force transducer was used to guide EMG amplitude at specific bite-force. The transducer was held in a stainless steel housing
and retained by the upper incisor teeth using an autopolymerizing acrylic resin jig (Duralay: Dental Mfg, IL, USA) (Fig1).

Subjects were asked to bite on a stainless steel platform attached to the steel housing and positioned parallel to the lower occlusal plane. As a result, the direction of bite-force recorded by the transducer was at right angles to the lower occlusal plane. The platform extended anteriorly to rest above the incisal edge of lower incisors. This ensured that the bite-force from the incisors, which contacted the platform, was directed down the center of the transducer housed in the stainless steel casing (Fig 2a). The jig was relined intraorally on the day of the experiment (Fig 2b).
During preliminary recordings the subjects complained of discomfort while biting on the platform at maximum bite force. A celluloid strip was placed on the biting surface of the platform to improve biting comfort.

Subjects were trained before recordings, to determine bite-force levels at maximum and half-maximum bite-force. Visual feedback was used to assist subject training. AMLAB data-acquisition system (Associative Measurements, North Ryde, Sydney, Australia) at a sampling rate per channel of 4200 samples/s and with a bandwidth of 2100 Hz, were used to determine bite-force level.

3. Leaf-gauge recording

In an earlier study (Long 1973), a method was described for locating CR with a leaf-gauge. A leaf-gauge was composed of rectangular shaped leaves of celluloid (0.25–0.50 mm thick). Several leaves were placed between each subject’s incisor teeth so that posterior tooth contact was eliminated. Leaves were removed until posterior contact was just made; then one additional leaf added so that the posterior teeth were out of contact.

In this series of recordings, the mandible was held closed on the leaf-gauge for 5 seconds with two levels of bite-force: maximum bite-force (hard), and half-maximum bite-force (moderate). If the subject sensed posterior tooth contact an additional leaf was added to avoid posterior tooth contact. The mandibular incisors occluded on the leaf-gauge and this anterior tooth contact influenced spatial jaw and condyles position.
4. Jaw movement recording

Condylar and mid-incisor point (MIPT) movements were recorded with an opto-electronic jaw tracking system (JAWS-3D; Metropolis AG, Zurich, Switzerland, sampling rate = 67 Samples/s). One target frame was attached the maxilla and the other to the mandible using rigid clutches (Fig 2b) as described by Peck et al. (1997). The clutches were cast in semiprecious metal and designed to provide full buccal coverage of two or three teeth in the canine region. If the occlusion permitted, an occlusal extension was included to increase clutches stability. Cyanoacrylate adhesive (Loctite, Loctite Australia NSW, Australia) was used to secure the clutches to the teeth. The occlusion was checked to ensure that the clutches did not interfere with intercuspal position or anterior jig or leaf gauge contact.

An aluminum tube was attached to each clutch with auto-polymerizing resin (Duralay, U.S.A.) and lightweight, plastic target frames carrying light emitting diodes (LED) were attached to the tubes. These frames enabled recording of MIPT and palpated lateral condylar pole with the JAWS-3D opto-electronic system, which used three, one-dimensional optosensor cameras to record the relative positions of the target
frames (Fig 3 & Fig 4). However, only the MIPT in the horizontal plane was displayed as a dot (termed MIPT dot) on the video screen for the participant to track and this was derived from the JAWS-3D system on-line. The JAWS-3D tracking system recorded the motion of the target frame and then, off-line, could also calculate the motion of any point subsequently selected. All jaw movements started from the postural jaw position.

The condylar point was used for the primary reference point, and MIPT was used for the secondary reference point. During recordings, subjects were asked to sit upright and were instructed to bite on the leaf-gauge at two levels of bite-force (see Peck et al 1999), half-maximum and maximum following pre-recording training.

5. Tasks

All participants were asked to perform a series of clenching tasks. At the beginning of the trial, the subject held the jaw in the relaxed postural jaw position for 5 seconds. A red LED light located at subjects' eye level was the signal for the subject to clench for 5 seconds; another signal to instruct the subject to relax. Total recording time was
approximately 20 seconds. Each subject performed different clenching tasks as follows:

1. Clenching from rest position to an intercuspal position at maximum bite-force represented the control
2. Clenching with the anterior jig at maximum bite-force
3. Clenching with the anterior jig at half-maximum bite-force
4. Clenching with the leaf-gauge at half-maximum bite-force
5. Clenching with the leaf-gauge at maximum bite-force.

A series of 5 or more trials were recorded for each task, with 2 minutes rest between the tasks. Condylar displacements were recorded in antero-posterior (x), medio-lateral (y) and supero-inferior (z) axes (Fig 5). The positive for the x-, y- and z-axes are posterior, lateral, and superior, respectively. All recordings were taken from the right side of each subject.
Results
The data of subjects RS, SF, SP and MA were analyzed. Subject PA’s data was not included due to the technical errors including clutch detachment and excessive subject movement during the trial. Condylar point movement along each of the three axes as described under tasks in the methods section was smoothed at a 60-point moving average applied 10 times.

As previously described, a series of 5 or more trials were carried out for each of the required tasks. The raw values for the JAWS-3D data were averaged within the task timeframe (e.g. 5 to 10 seconds) and the unit of average condylar displacement was millimeters per second. This was achieved using the JAWS-3D plots and the coordinates recorded in the data files. The numerical values in the Tables are mean values of the displacement in each trial, with postural jaw position as the reference point. The displacement may be negative or positive depending on the direction of condyle movement. In some trials, either negative or positive values were obtained for the same task. The percentage of this occurrence is indicated in brackets in the Tables. The hash symbol indicates the absence of values for that particular axes (x, y, z) direction.

Table 1 contains data from subject SP who had edge-to-edge incisor relationship. RS and SF both had Angle Class I incisor relationships and their data is listed in Table 2. Table 3 shows data for subject MA with Angle Class II Div II incisor relationship. As indicated, jaw displacement is represented in the following manner:

1. X- represents the antero-posterior displacement for which posterior is positive
2. Y- represents the medio-lateral displacement for which lateral is positive.

3. Z- represents the supero-inferior displacement for which superior is positive.

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>TASK</th>
<th>BITE-FORCE</th>
<th>JAW DISPLACEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>SP</td>
<td>Control</td>
<td>Max</td>
<td>P #</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A -0.36</td>
</tr>
<tr>
<td>Jig</td>
<td>Half</td>
<td>Max</td>
<td>P 0.05 (1 trial-20%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A -0.27 (4 trials-80%)</td>
</tr>
<tr>
<td></td>
<td>Half</td>
<td>Max</td>
<td>P #</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A -0.93</td>
</tr>
<tr>
<td>Leaf-gauge</td>
<td>Half</td>
<td>Max</td>
<td>P 0.15 (2 trials-40%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A -0.26 (3 trials-60%)</td>
</tr>
<tr>
<td>Leaf-gauge</td>
<td>Max</td>
<td>P #</td>
<td>L 0.15 (1 trial-20%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A -0.64</td>
</tr>
</tbody>
</table>

Table 1. Subject with edge-to-edge incisor relationship. Table 1 shows the mean values of condyle displacement for each task in antero-posterior (x), medio-lateral (y) and supero-inferior (z) directions. (A, anterior; P, posterior; M, medial; L, lateral; S, superior and I Inferior). The unit of displacement is millimeters per seconds. The value in brackets represents the number of trials, the data of which was combined to produce the displacement shown.
<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>TASK</th>
<th>BITE-FORCE</th>
<th>JAW DISPLACEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X</td>
<td>y</td>
</tr>
<tr>
<td>RS</td>
<td>Control</td>
<td>Max</td>
<td>P #</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A  -0.70</td>
<td>M #</td>
</tr>
<tr>
<td>Jig</td>
<td>Half</td>
<td>P 0.68</td>
<td>L 0.08 (3 trials-75%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A #</td>
<td>M -0.19 (1 trial-25%)</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>P 0.43</td>
<td>L 0.14 (3 trials-50%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A #</td>
<td>M -0.16 (3 trials-50%)</td>
</tr>
<tr>
<td>Leaf-gauge</td>
<td>Half</td>
<td>P 0.32 (4 trials-80%)</td>
<td>L 0.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A - 0.32 (1 trial-20%)</td>
<td>M #</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>P 0.09</td>
<td>L 0.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A #</td>
<td>M#</td>
</tr>
<tr>
<td>SF</td>
<td>Control</td>
<td>Max</td>
<td>P 0.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A #</td>
<td>M -0.78 (3 trials-60%)</td>
</tr>
<tr>
<td>Jig</td>
<td>Half</td>
<td>P #</td>
<td>L 0.19 (1 trial-20%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A -0.16</td>
<td>M - 0.15 (4 trials-80%)</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>P #</td>
<td>L #</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A -0.25</td>
<td>M -0.16</td>
</tr>
<tr>
<td>Leaf-gauge</td>
<td>Half</td>
<td>P 0.36 (4 trials-67%)</td>
<td>L 0.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A - 0.24 (2 trials-33%)</td>
<td>M #</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>P 0.40</td>
<td>L 0.20 (5 trials-84%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A #</td>
<td>M -0.11 (1 trial-16%)</td>
</tr>
</tbody>
</table>

Table 2. Subjects with Angle Class I incisor relationship. Table 2 shows the mean values of condyle displacement for each task in antero-posterior (x), medio-lateral (y) and supero-inferior (z) directions. (A, anterior; P, posterior; M, medial; L, lateral; S, superior and I Inferior). The unit of displacement is millimeters per seconds. The value in brackets represents the number of trials, the data of which was combined to produce the displacement shown.
<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>TASK</th>
<th>BITE-FORCE</th>
<th>JAW DISPLACEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA</td>
<td>Control</td>
<td>Max</td>
<td>P 0.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>-0.23 (5 trials-86%)</td>
</tr>
<tr>
<td>Jig</td>
<td>Half</td>
<td>P 0.19 (2 trial-40%)</td>
<td>L #</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A -0.24 (3 trials-60%)</td>
<td>M -0.35</td>
</tr>
<tr>
<td>Max</td>
<td>P #</td>
<td>L #</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A -0.40</td>
<td>M -0.36</td>
<td>S 0.67</td>
</tr>
<tr>
<td>Leaf-gauge</td>
<td>Half</td>
<td>P 0.039 (1 trial-20%)</td>
<td>L 0.05 (3 trials-60%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A -0.10 (4 trials-80%)</td>
<td>M - 0.11 (2 trials-40%)</td>
</tr>
<tr>
<td>Max</td>
<td>P 0.09 (2 trials-29%)</td>
<td>L 0.22 (2 trials-29%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A - 0.12 (5 trials-71%)</td>
<td>M - 0.22 (5 trials-71%)</td>
<td>S 0.78</td>
</tr>
</tbody>
</table>

Table 3. Subject with Class II Div II Angle incisor relationship. Table 3 shows the mean values of condyle displacement for each task in antero-posterior (x), medio-lateral (y) and supero-inferior (z) directions. (A, anterior; P, posterior; M, medial; L, lateral; S, superior and I Inferior). The unit of displacement is millimeters per seconds. The value in brackets represents the number of trials, the data of which was combined to produce the displacement shown.

Summary of condylar displacement taken from Tables 1, 2, 3.

<table>
<thead>
<tr>
<th>control</th>
<th>JIG</th>
<th>LEAF-GAUGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ MAX</td>
<td>MAX</td>
<td>½ MAX</td>
</tr>
<tr>
<td>RS (see Table 2)</td>
<td>ALS</td>
<td>PLS</td>
</tr>
<tr>
<td>SF (see Table 2)</td>
<td>PMS</td>
<td>AMS</td>
</tr>
<tr>
<td>SP (see Table 1)</td>
<td>AMS</td>
<td>AMS</td>
</tr>
<tr>
<td>MA (see Table 3)</td>
<td>PMS</td>
<td>AMS</td>
</tr>
</tbody>
</table>

Table 4. Summary of the most frequent condylar displacement values for a particular task, as presented in Tables 1-3. Numerical values of Tables 1-3 are not included. The letters used describe condyle displacement in three-dimensions – A = anterior; P = posterior; M = medial; L = lateral; S = superior and I = Inferior.
Fig 5. Typical JAWS-3D plots representing the 3D displacement of the condyle. Displacements are represented by: (---) for antero-posterior, (-----) for medio-lateral and (...) for the postero-inferior. The x-axis is time in seconds and the y-axis is displacement in millimeters. Post-med-up represents the postero-medio-superior displacement of the condyle in this trial.

Use of load cell allowed the subjects to bite consistently on the leaf-gauge at the prescribed levels of bite-force. Postural jaw position was used as the reference for all biting tasks. The relationship of the leaf-gauge to the incisor teeth at maximum bite-force was seen to vary in the following ways:

1. Angle Class I incisor relationship - the leaf-gauge was retained at approximately 45° to the horizontal.

2. Angle Class II div 2-incisor relationship - the leaf-gauge was retained at approximately 75° to the horizontal.
3. Angle Class III incisor relationship - the leaf-gauge was retained almost horizontal.
Discussion

This pilot study analyzed the effect on condyle position of biting at different bite-force levels, using a leaf-gauge and an anterior jig. Subjects had different incisor relationships, which influenced the effect on condyle positions.

1. Condylar displacement recording

During the execution of the tasks, the inter-incisal distance between the postural jaw position and the recording positions was small and condylar displacement was minimal. This is evident in Tables 1-3, where in some situations this displacement was fractional and almost non-existent. The inherent error of the recording system (JAWS-3D) of 0.2 mm in any direction negated some displacement values.

1.1 The accuracy of JAWS-3D

Airoldi et al (1994) examined the accuracy of JAWS-3D recordings. Their results showed that the accuracy decreased when the distance between the recorded point and the extraoral landmarks increased. They estimated that the path of a point near the landmark had an error of 0.11%, whereas the error increased to 1.33% when the point was at a distance from the landmark. The maximum error in angle computation was 0.7 degrees. The velocities calculated by JAWS-3D corresponded closely to the actual ones: mean error of 3 mm/s for velocities up to 80 mm/s (3.75%). Thereafter, the error increased to 26 mm/s at a speed of 210 mm/s (12.39%). There is an estimated 0.2 mm error in all planes.
Airoldi and colleagues concluded that the small error of JAWS-3D together with its low invasiveness supports its use in clinical research. However subject movement leading to inaccurate recordings influences the system. Interpretation of the results must recognize this limitation particularly where displacement is small.

It is evident that accurate assessment of condyle position is difficult due to the broad variation amongst subjects. The most significant obstacle is the choice of a reference point that represents condylar movement. A three-dimensional entity cannot be represented accurately by one particular reference point (Peck et al 1999).

2. **Biting on the leaf-gauge**

This investigation supports the results of Braun et al (1997) that the condyle does not reliably attain CR using the leaf-gauge at different levels of bite-force. In our study, postero-superior displacement occurred in two subjects, and antero-superior displacement in the remaining two subjects.

In the subject with a Class III incisor relationship, postero-inferior displacement did not occur in either control or leaf-gauge trials. A “tripodisation” effect with the leaf-gauge promoted antero-superior positioning of the condyle, particularly at maximum bite-force, which was almost equal to that of the control (Table 1). As indicated, the leaves were retained almost horizontally between the incisor teeth. This avoided the
“wedging effect” which could cause mandibular retrusion. It may be concluded that with edge-to-edge incisor relationship the leaf-gauge could promote a CR position. A larger study is clearly required.

In subjects with an Angle Class I incisor relationship, the condyle was not positioned anteriorly at maximum and half-maximum bite-force (Table 2). This questions the claim that in all cases, the leaf-gauge promoted a physiologic condylar position against the articular disc and the eminence. This data excluded inferior and medial displacement. For subject SF, the degree of superior displacements was similar at maximum and half-maximum bite-forces.

Posterior condylar displacement in subject RS was 0.09 mm/sec at maximum bite-force. This was negligible and is within the error range of JAWS-3D.

In the subject with Angle class II div II, the leaf-gauge displaced the condyle antero-superiorly at all bite-force levels (Table 3). The expected “wedging effect” of the leaf-gauge due to the deep incisor overbite/overjet relationship, did not take place. A possible explanation was proposed by Tradowsky and Kubicek (1981), who suggested that the mandible acts as a Class III lever if the load was placed on the anterior teeth. They claimed that the condyle would be displaced postero-superiorly with the distal component of force provided by the lingual slopes of the maxillary anterior teeth. Conversely, our results differ from those of Golsen and Shaw (1984) who concluded that the condyle moved
postero-inferiorly with the use of the leaf-gauge. However their conclusion was not based on experimental data but only on clinical assessment.

Use of the leaf-gauge showed variation in the quantity of superior displacement in different subjects. The increase in bite-force did not appear to play a major role in the amount of displacement, in all subjects. For subject RS the displacement at half-bite force was double that at full bite-force. Conversely, in the case of subject MA, the displacement at full bite-force was double that at half bite-force.

Fenlon and Woelfel (1993) found that tripodisation with the leaf-gauge, resulted in displacement of the condyles in a superior direction with little antero-posterior movement. Our study is in agreement as our data did not show inferior condylar displacement.

Our study appears to support the conclusion of Williamson et al (1980) in some cases. In our study we used 5-10 seconds of biting time, whereas Williamson and his colleagues used 5 minutes. It is questionable whether it is possible for subjects to maintain maximum bite for such long periods without developing muscle fatigue. In addition, their study did not look at the effect of the dentition on displacement.
3. Biting on the anterior jig (load Cell)

Solow (1999) and Carroll et al (1988) used an inclined plane anterior jig, whilst Becker et al (1999) used a prefabricated flat plane anterior jig. Our study used a flat plane jig, which retained the load cell. The initial purpose of the device was to train subjects on levels of bite force, in preparation for the leaf-gauge. However, our data obtained whilst biting on the jig varied with the incisor relationship and the depth of the palate, the bite point was located on the IP arc of closure. This was not the position used for CR recordings. In contrast, the jig used by Lucia (1964) formed an inclined plane and reduced the interocclusal molar separation; with a flat plane jig this may also be achieved but it must not be too bulky.

The load cell with class II div II incisor relationship resulted in a superior condylar displacement of almost half that of control at both levels of bite-force (Table 3).

For the subject with class III incisor relationship, antero-superior movement occurred at both levels of bite-force (Table 1). Greater superior displacement occurred at half bite-force. However anterior displacement at maximum bite-force was almost three times that of both control and half-bite force.

Fenlon and Woelfel (1993) used a similar load cell and concluded that at loads of 50 N and 100 N the difference in superior displacement was about 0.09mm. In our study, condylar displacement in the superior direction was comparable between the two levels of bite-force in subjects RS, SF and MA. The “condyle
drop” or inferior displacement, suggested by Kantor et al (1972) did not occur with the use of the anterior jig.

Our results neither support nor contradict the conclusion of Lundeen (1974) who used the Buhnergraph (Dental Items, Inc., Tipp City, Ohio.) to compare condylar positions obtained by two methods of making interocclusal records, including the anterior jig. Lundeen claimed that biting lightly on the anterior jig promoted a “more physiological” condylar position. Our data resulted in more consistent results with maximum bite-force. There was no evidence to indicate that this is “more physiological”.

Wood et al (1994) designed a study to investigate the relationship between different biting forces and condylar position. Subjects were asked to bite on the anterior strain gauge while the mandible was in hinge axis position. They concluded that as the bite-force increased so did the condylar positioning in the anterior and superior directions (as did Lundeen 1974). However, the authors admitted that the amount of condylar displacement varied between individuals.

In the current study, condylar displacements varied between subjects when asked to bite on the strain gauge. This was similar to Wood and colleagues’ (1994) conclusion. Using the load cell, superior displacement in subject RS was double that of control. On the other hand, in subject SF, this displacement was similar at all levels of bite-force and control.
Teo and Wise (1981) reported the position of the horizontal axis of the condyle when jaw records were taken from subjects using: (a) an anterior jig with chin point guidance; (b) an anterior jig with chin point guidance and applied force by the subject; and finally (c) an anterior jig with bilateral manipulation. The results suggested that the most superior positions were obtained with the anterior jig and applied muscle force, which was not the most consistent method. Our study also showed inconsistency in condylar position using the anterior jig.

Biting on the anterior jig may be more stable than biting on the leaf-gauge. The biting platform increased incisal separation and created a less steep angle of guidance against which the mandibular incisors might exert force. In contrast, the thin flexible leaf-gauge causes minimal incisal opening and readily conforms to the concave maxillary incisor cingulum, thereby creating a steeper guidance above the occlusal plane. It is believed that when the mandibular incisors exert force against this steeply inclined plane, the resultant rotation or pivoting of the mandible caused by this anterior fulcrum, may position the condyles into the uppermost part of the articular fossae.
Conclusion.

This pilot study analyzed the condyle position with biting at different force levels, using a leaf-gauge and an anterior jig, in subjects with different incisor relationships. The method was developed using 3 subjects and the data of the subsequent 4 subjects were analyzed. We can conclude that the leaf-gauge did not in all cases produce an antero-superior position of the condyles, in the supposed CR position. Superior condylar displacement was a common element in the subjects studied, at various incisor relationships. Anterior displacement was more frequent using the anterior jig compared with the leaf-gauge, in most subjects. It is not possible to determine that the jig or the leaf-gauge leads to “physiologic” condylar position. It is possible that mandibular flexure, with higher bite-force levels, may be a contributing factor to the condylar displacement. This was not measured.

It is recommended that further studies be carried out on a larger group of subjects with differing incisor relationships.
References:


Golsen LF and Shaw AF 1984. Use of leaf gauge in occlusal diagnosis and therapy. Quintess Internat 6: 611-621


